Beauty Production and Identification at CMS

Alexander Schmidt

Universität Zürich
Physik-Institut

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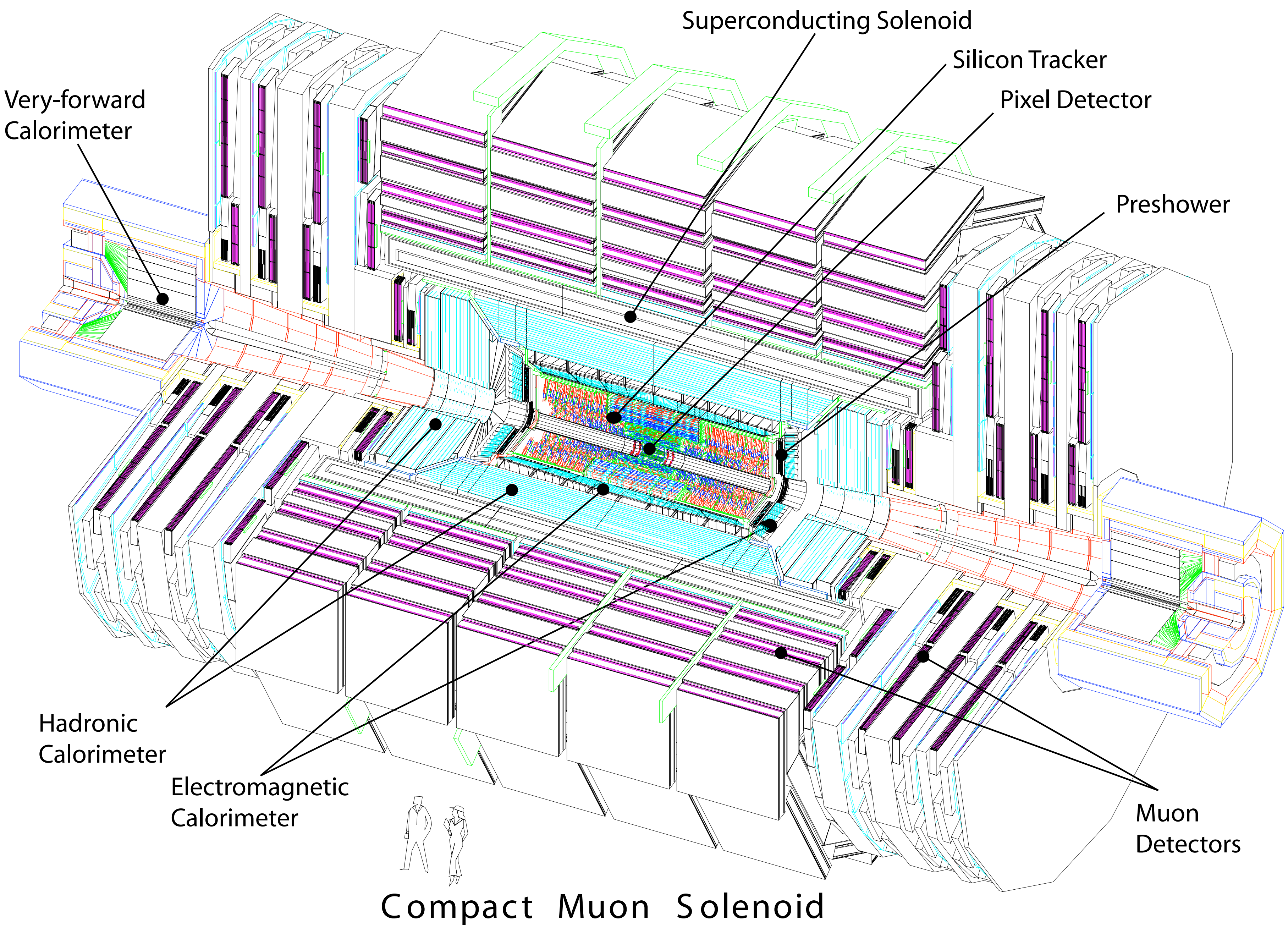
Outline

- the CMS detector
- b-production in hadron collisions
- applications of b-identification methods
- some technical details about b-tagging at CMS and expected performance
- prospects for inclusive b-production measurement
- further methods of measuring flavour fractions in jets

CMS Detector



magnet:
4 Tesla superconducting solenoid
successfully tested

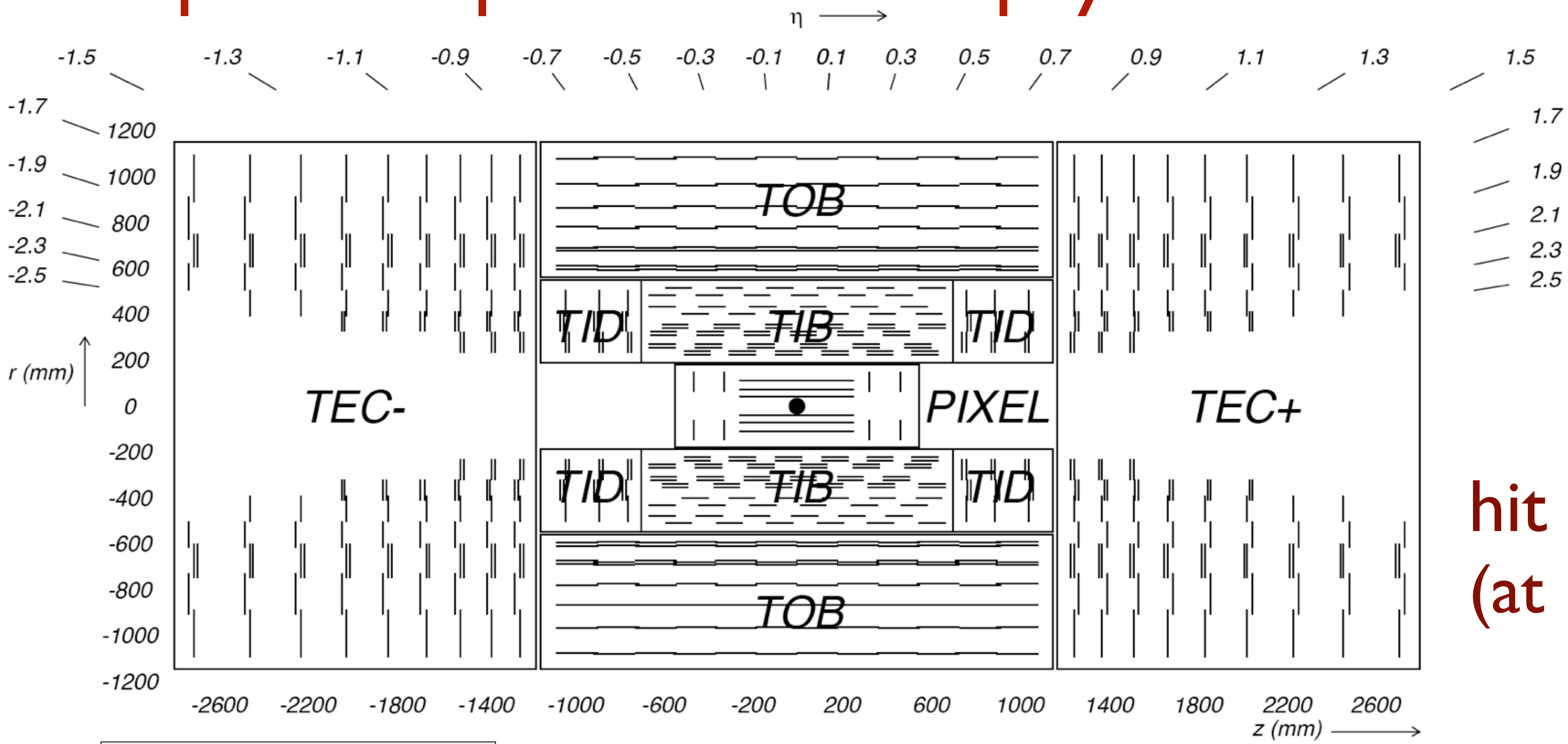
calorimeters:
ECAL: 76000 crystals of $PbWO_4$
HCAL: brass absorber + scintillator sandwich

muon system:
barrel: drift tubes
endcap: cathode strip chambers
barrel+endcap: resistive plate chambers

trigger:
40 MHz bunch crossing rate reduced to 100Hz by Level-1 and High Level Triggers

Silicon Tracker

of special importance for b-physics:



is the largest ever built:

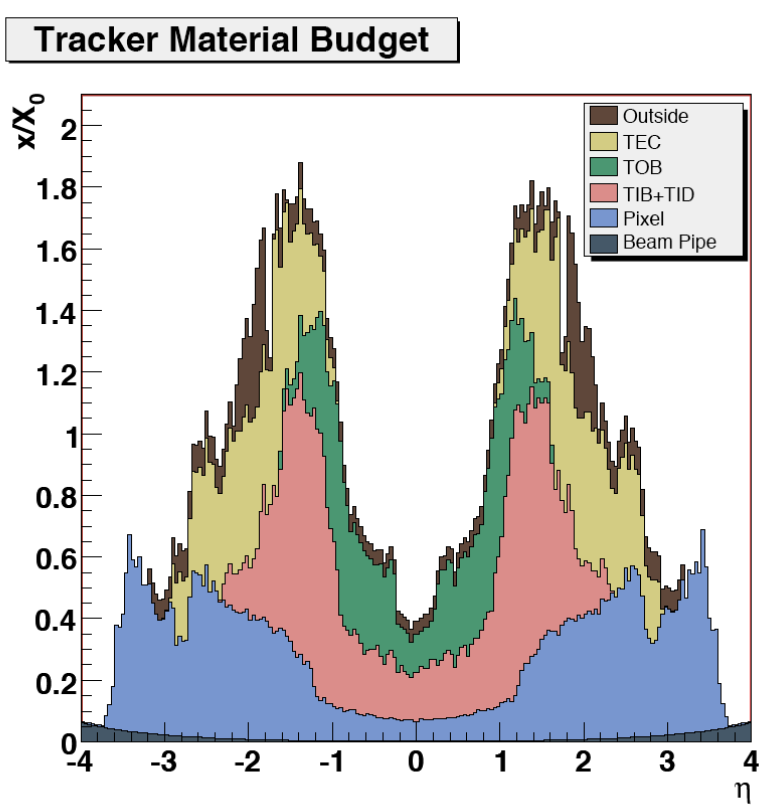
200m² of active silicon

1440 pixel modules

15148 strip detector modules

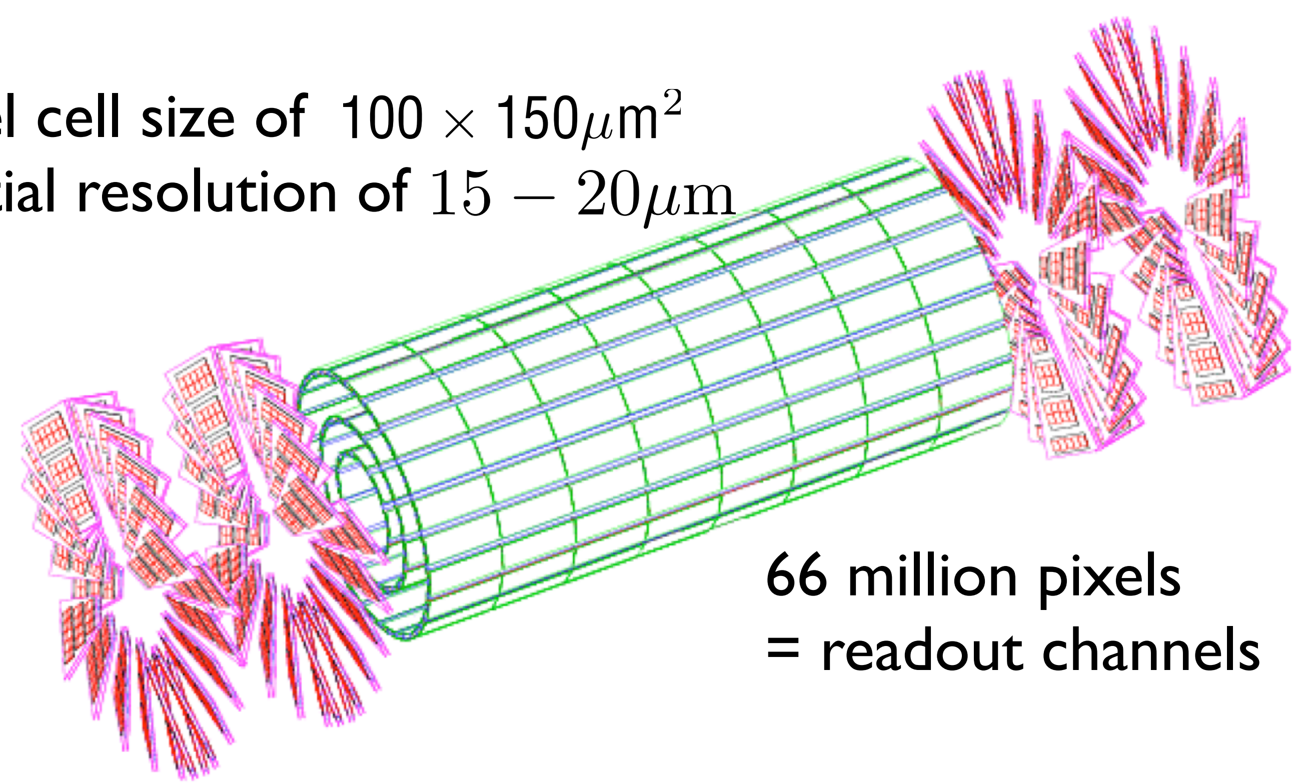
hit rate density of 1MHz/mm²

(at radius of 4cm)



pixel cell size of $100 \times 150 \mu m^2$

spatial resolution of $15 - 20 \mu m$



66 million pixels
= readout channels

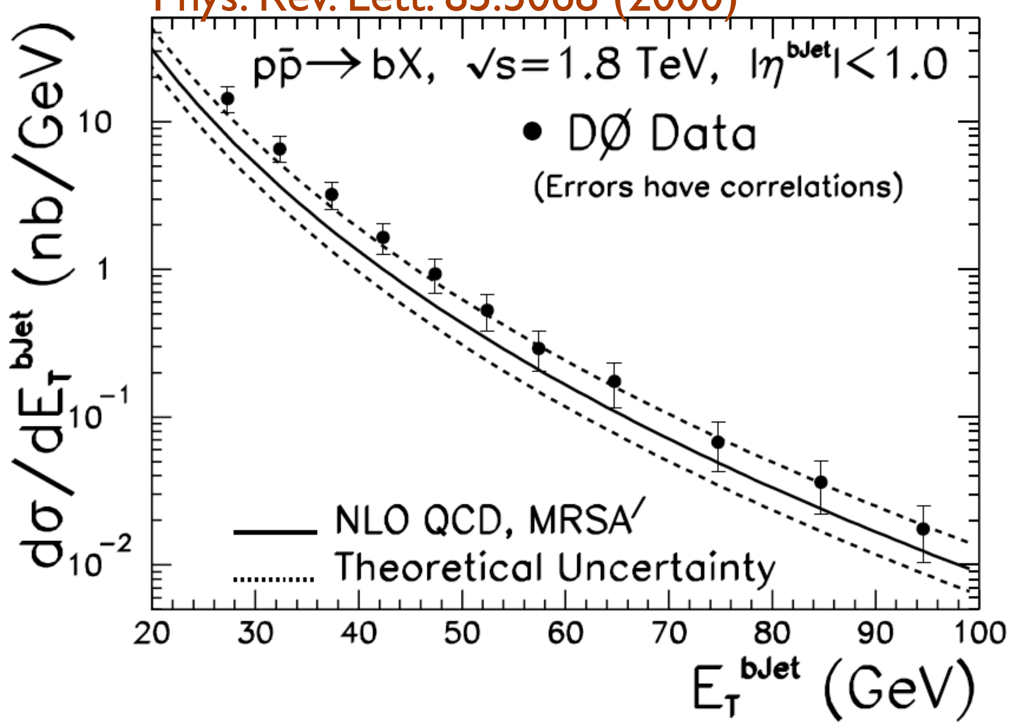
b Production in Hadron Collisions

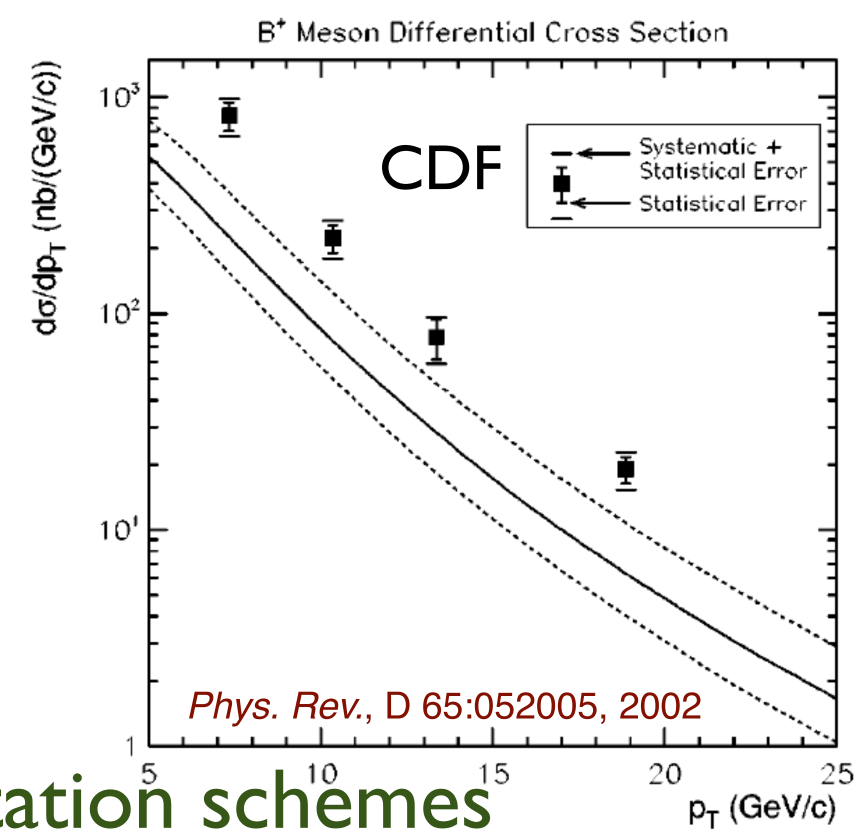
the b quark production cross-section was first measured by UA1 at CERN in 1988 at $\sqrt{s} = 630\mathrm{GeV}$

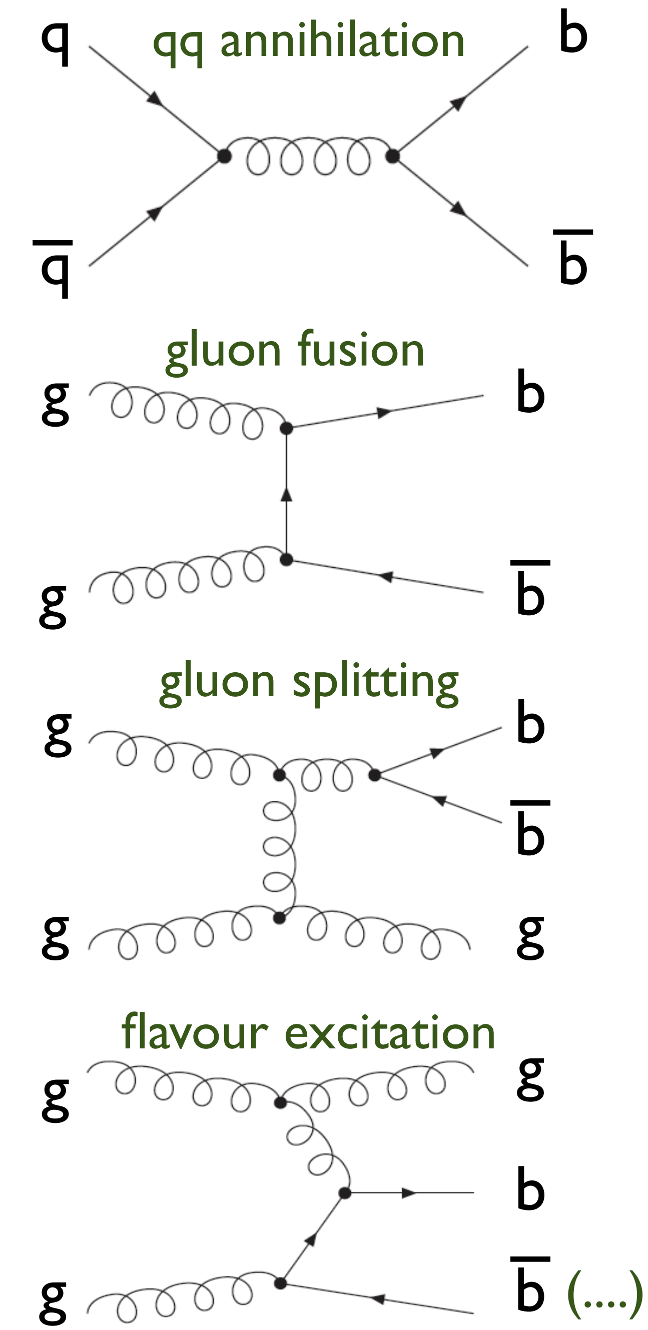
$\sigma(p\bar{p} \rightarrow b\bar{b} + X) = 10.2 \pm 3.3\mu\mathrm{b}$ (Phys. Lett. B213 (1988) 405)

later measurements at CDF and D0 showed significant deviations from calculations (initially factor >2) even when running at UA1 energy:
(also at HERA and LEP)

Phys. Rev. Lett. 85:5068 (2000)







meanwhile, updated fragmentation schemes reduced the discrepancy

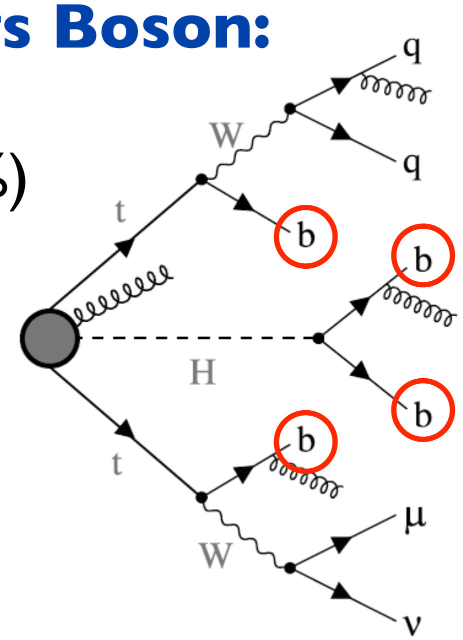
=> looking forward to LHC results at much higher transverse energies

Further Sources of b Quarks

b quarks play a crucial role in the search for new physics at LHC:

Standard Model Higgs Boson:

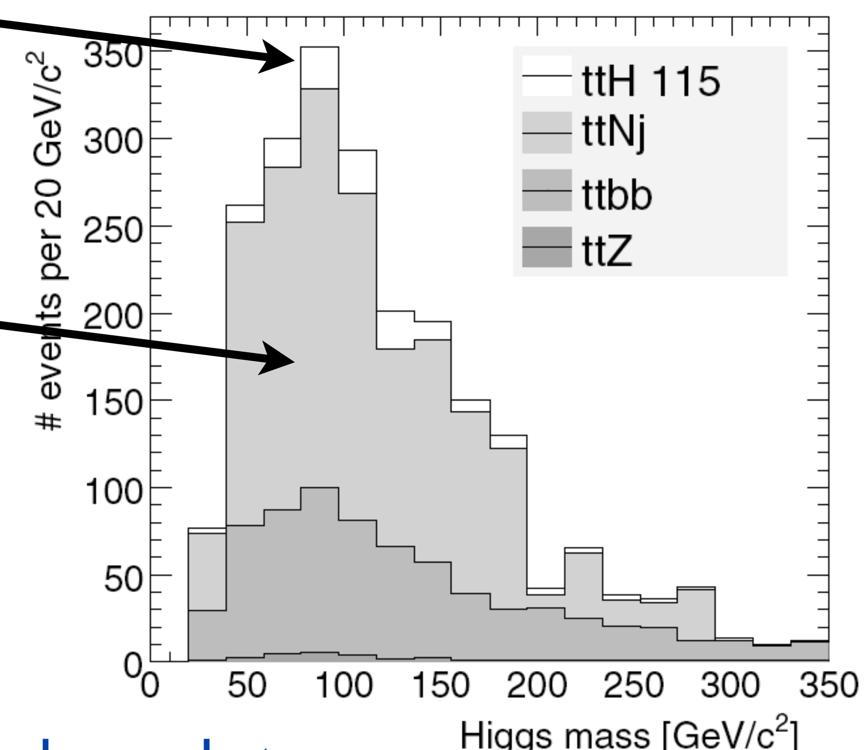
- decays into $b\bar{b}$ for low Higgs masses (B.R. > 50%)
- candidate channel: association with top
- suffers from $t\bar{t}$ + jets backgrounds



Higgs signal

background from mis-identified jets

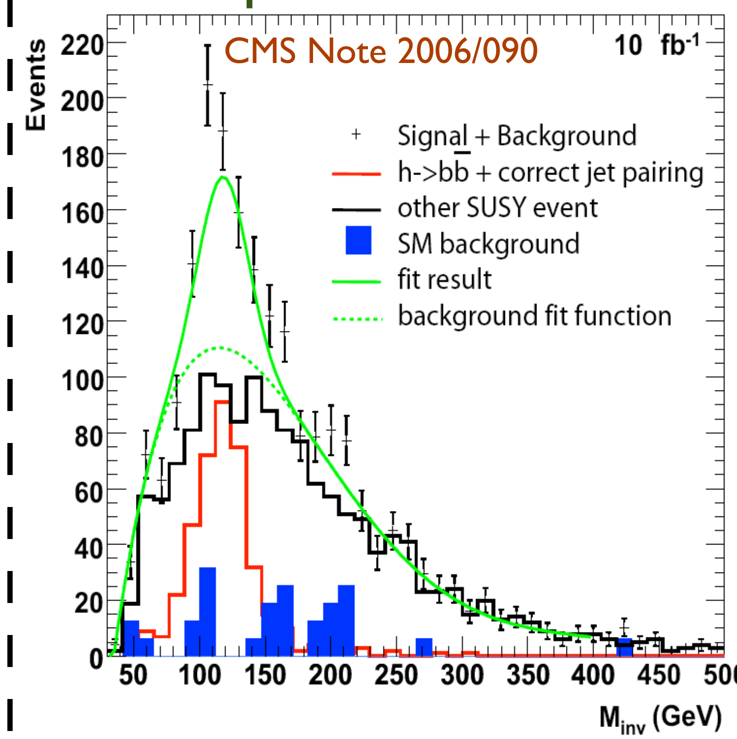
J. Phys. G: Nucl. Part. Phys. **34** (2007) N221–N250

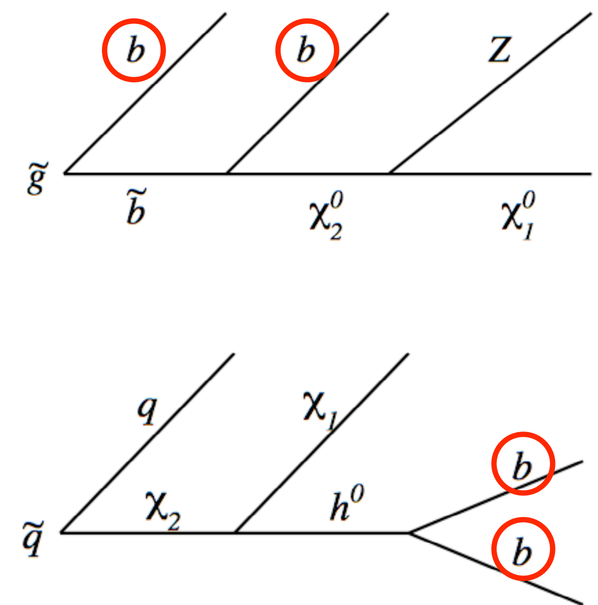


=> more work needs to be done in this case

SUSY decay chains lead to final sates with $b\bar{b}$:

example h^0 at LM5:



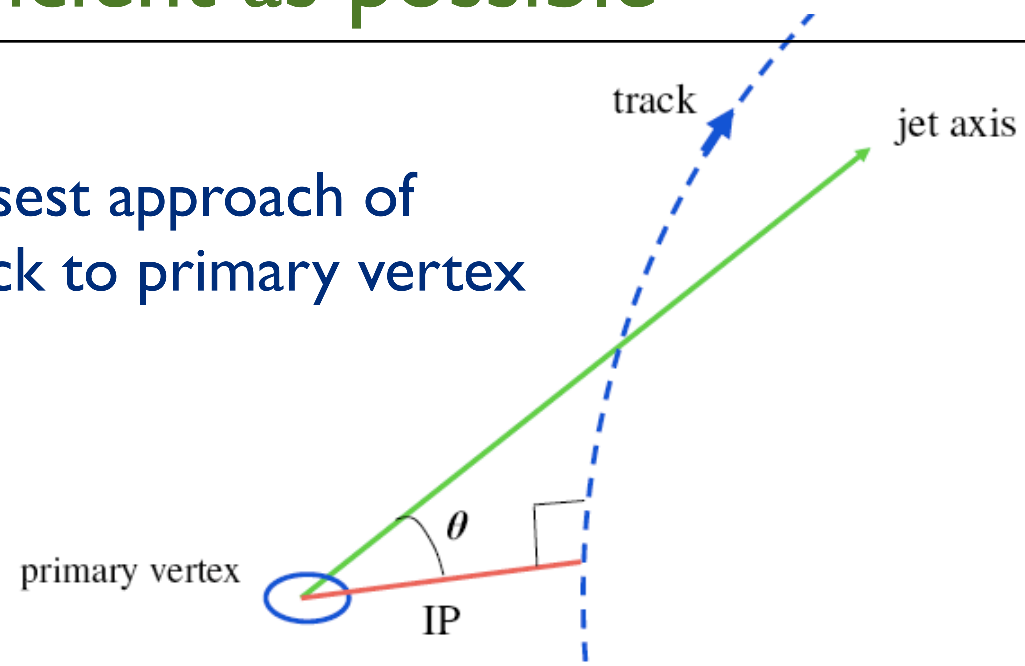


an accurate knowledge of the $b\bar{b}$ production rate is critical for an understanding of backgrounds in many BSM searches

Observables used for b-Tagging

goal: identify b-decay in jet as efficient as possible

closest approach of track to primary vertex

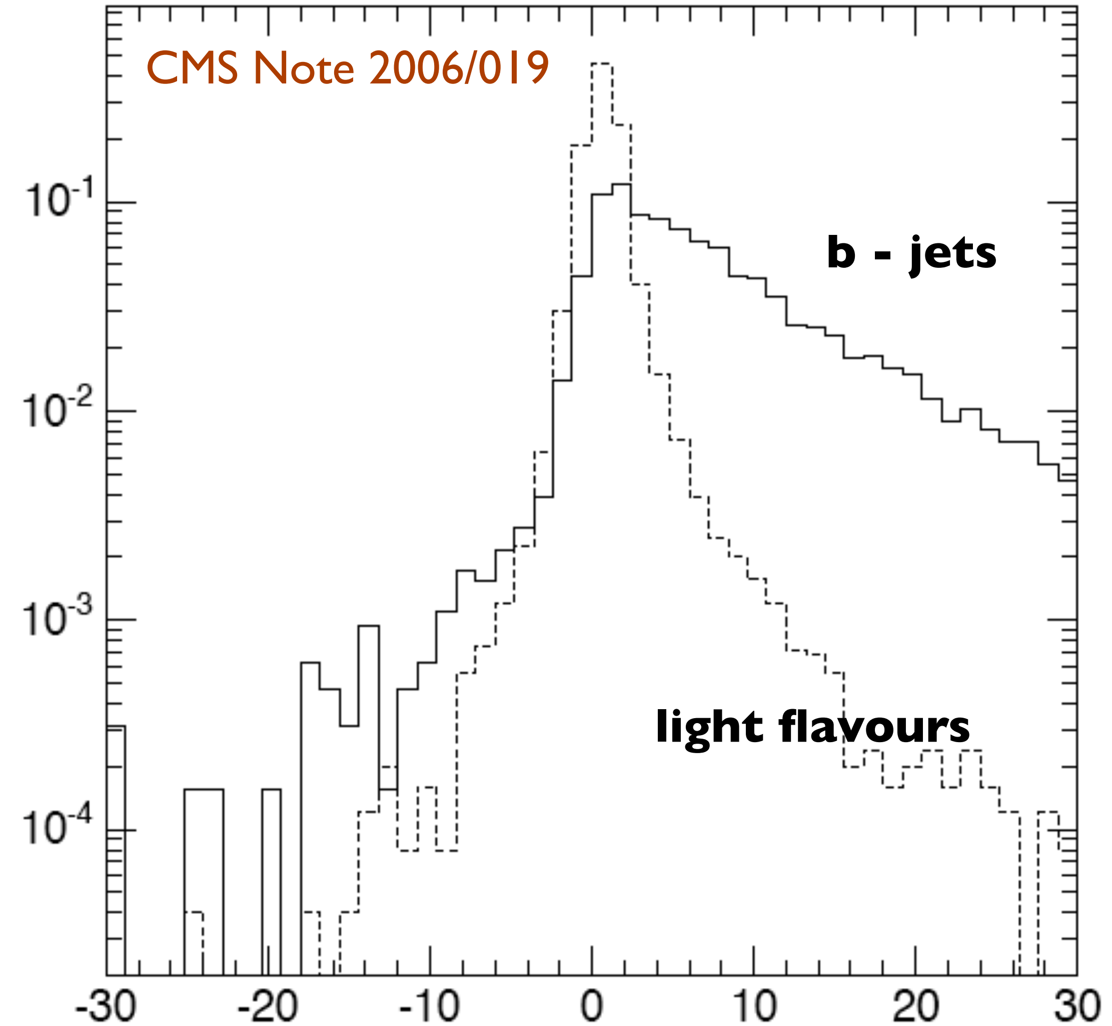


positive (negative) if decay occurs upstream (downstream) the jet direction.

other observables based on ***secondary vertex***:

- flight distance (separation from primary vertex)
- invariant mass at vertex (large b mass compared to c)
- number of tracks at vertex (on average 5 for b)
- ....

include all available information into combined tagging algorithms based on Likelihood methods or neural networks



Impact Parameter Significance of 2nd track

=> using significance of second track

(ordered by the significance itself)

because first track is likely to be mismeasured.

second track => higher efficiency

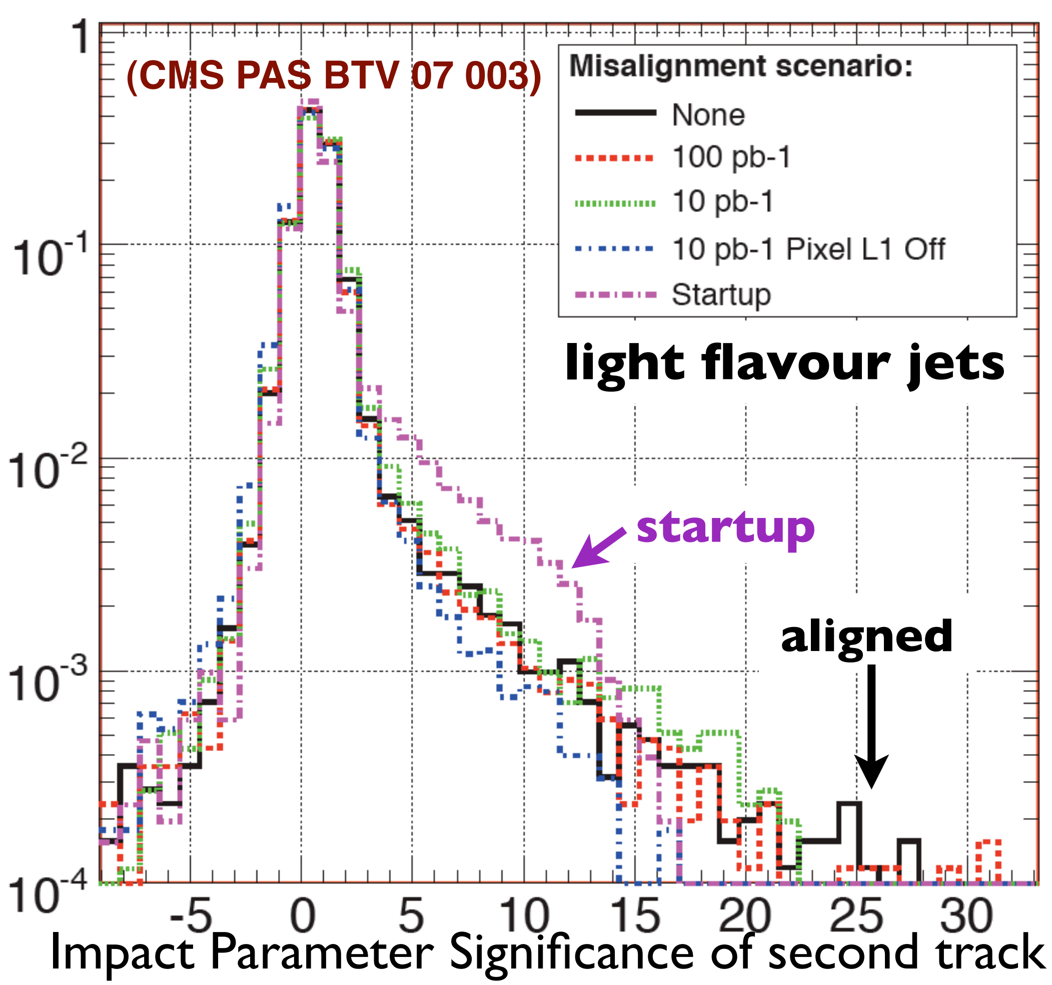
third track => higher purity

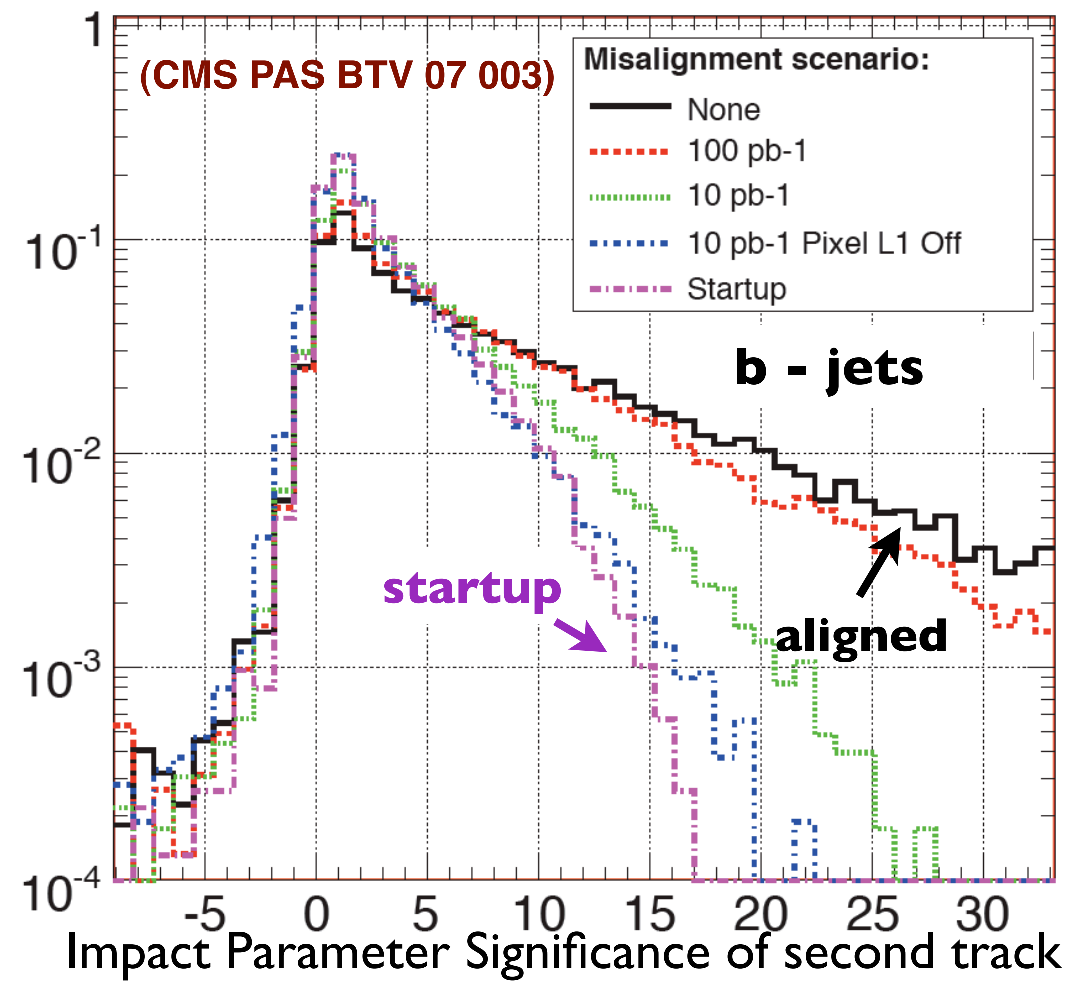
Detector Alignment

the achievable performance strongly depends on detector alignment and calibration.

scenarios under study:

- **startup:** installation precision + survey + cosmics (e.g. $20\mu m$ for pixel barrel sensors)
- **first collisions: 10pb^{-1}:** using low mass resonances like J/psi and Upsilon improvement by a factor of ~5 for pixel detector
- **100pb^{-1}:** using high mass resonances like W and Z
- **1000pb^{-1}:** tracker can be considered to be aligned





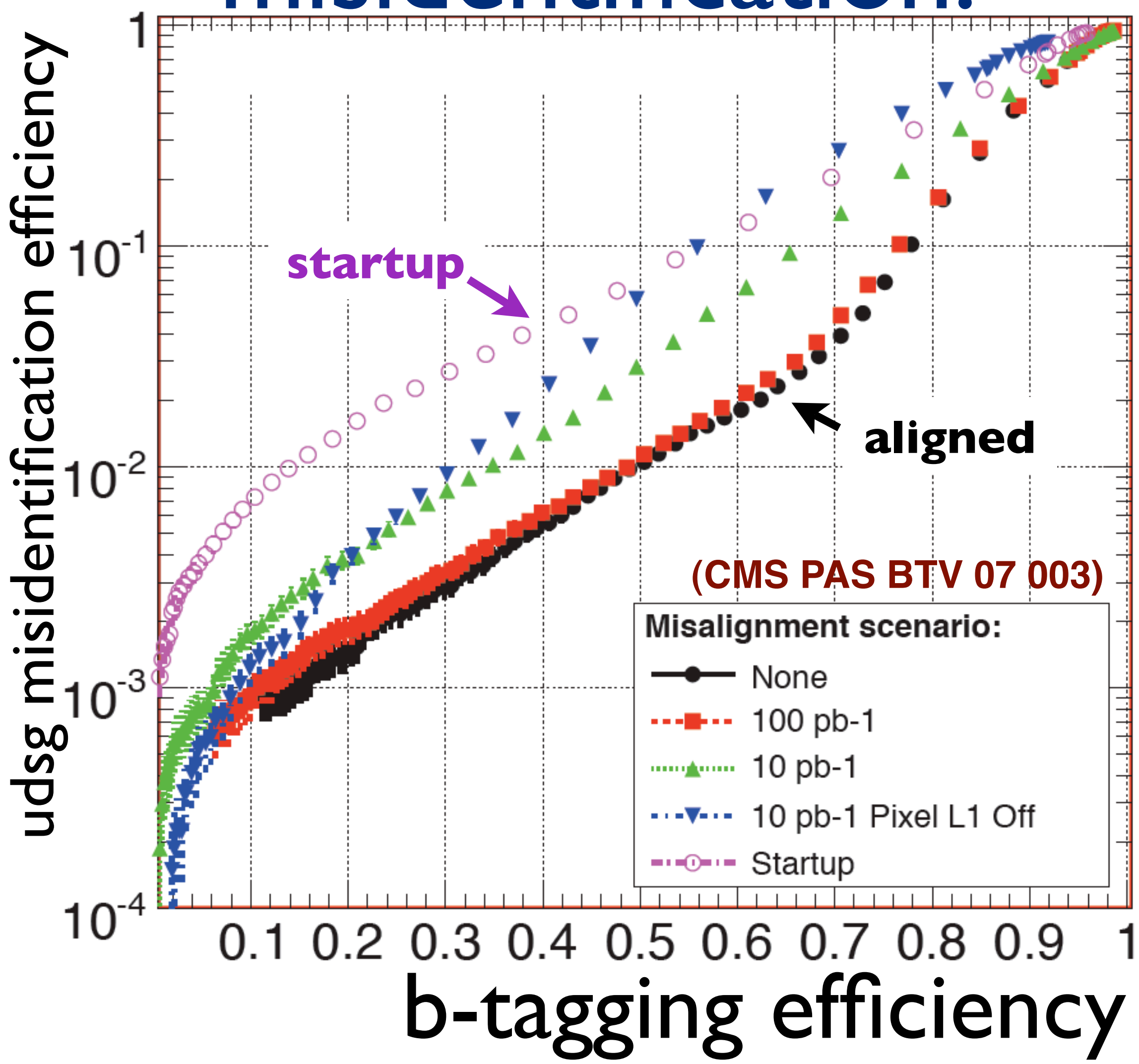
=> broader for startup due to large fake track rate (IP value larger)

=> more narrow for startup due to large measurement errors (IP error larger)

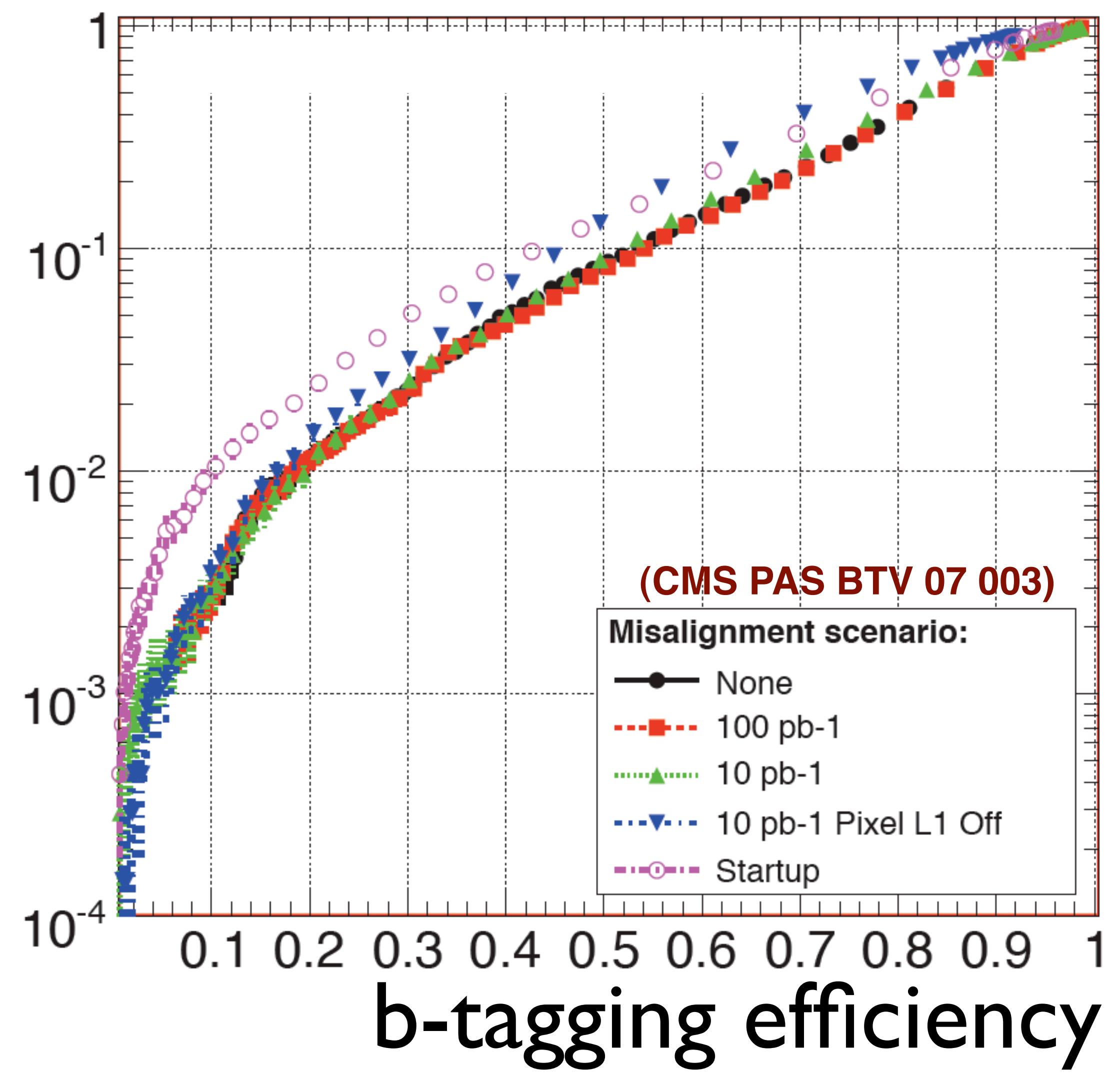
Performance of b-Tagging (I)

example: impact parameter based b-tagging
(using second track, ordered by IP)
- very simple, does not require training of any kind (likelihood, NN)
  => application with first data is straightforward
- still reaches high purities
- but it is quite sensitive to misalignment

light flavour misidentification:



charm misidentification:

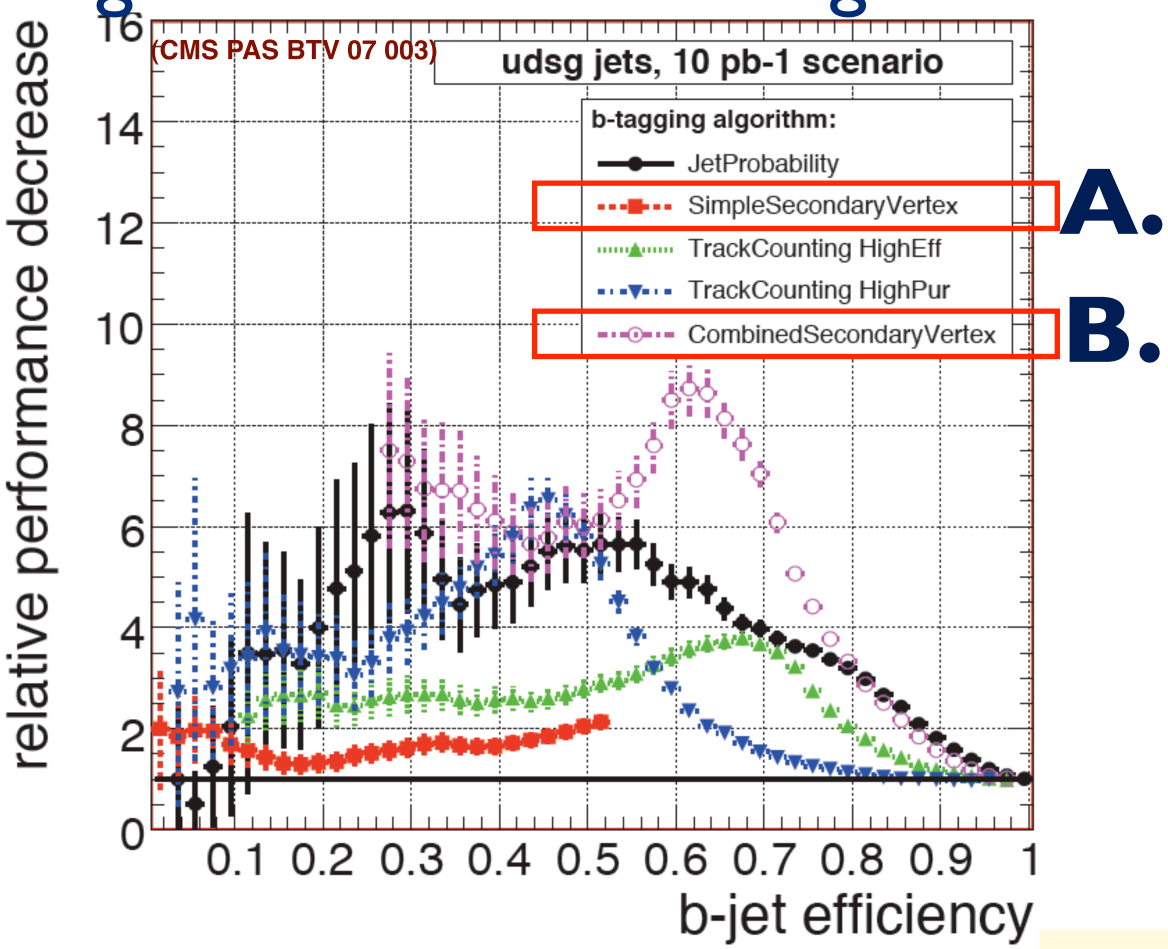


Performance of b-Tagging (II)

secondary vertex based b-tagging, two examples:

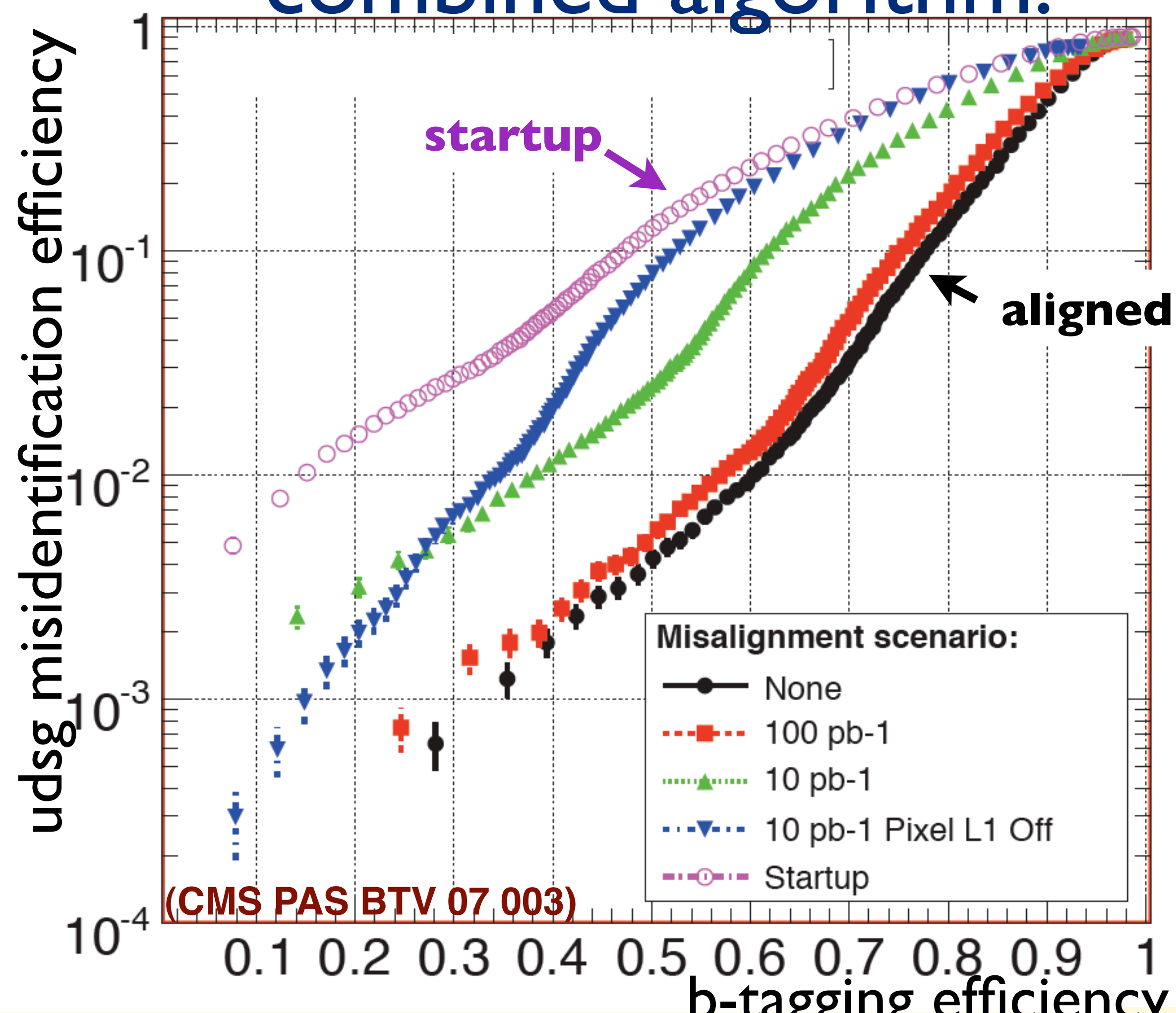
A. secondary vertex only,
using flight distance significance:
- also very simple, no training
- still reaches high purities
- turns out to be robust against misalignment
- limited to SV finding efficiency
  => 2% mis-tags at 65% b-efficiency
  (startup: 3% mis-tags at 35% b-efficiency)

decrease of performance with misalignment for various algorithms:



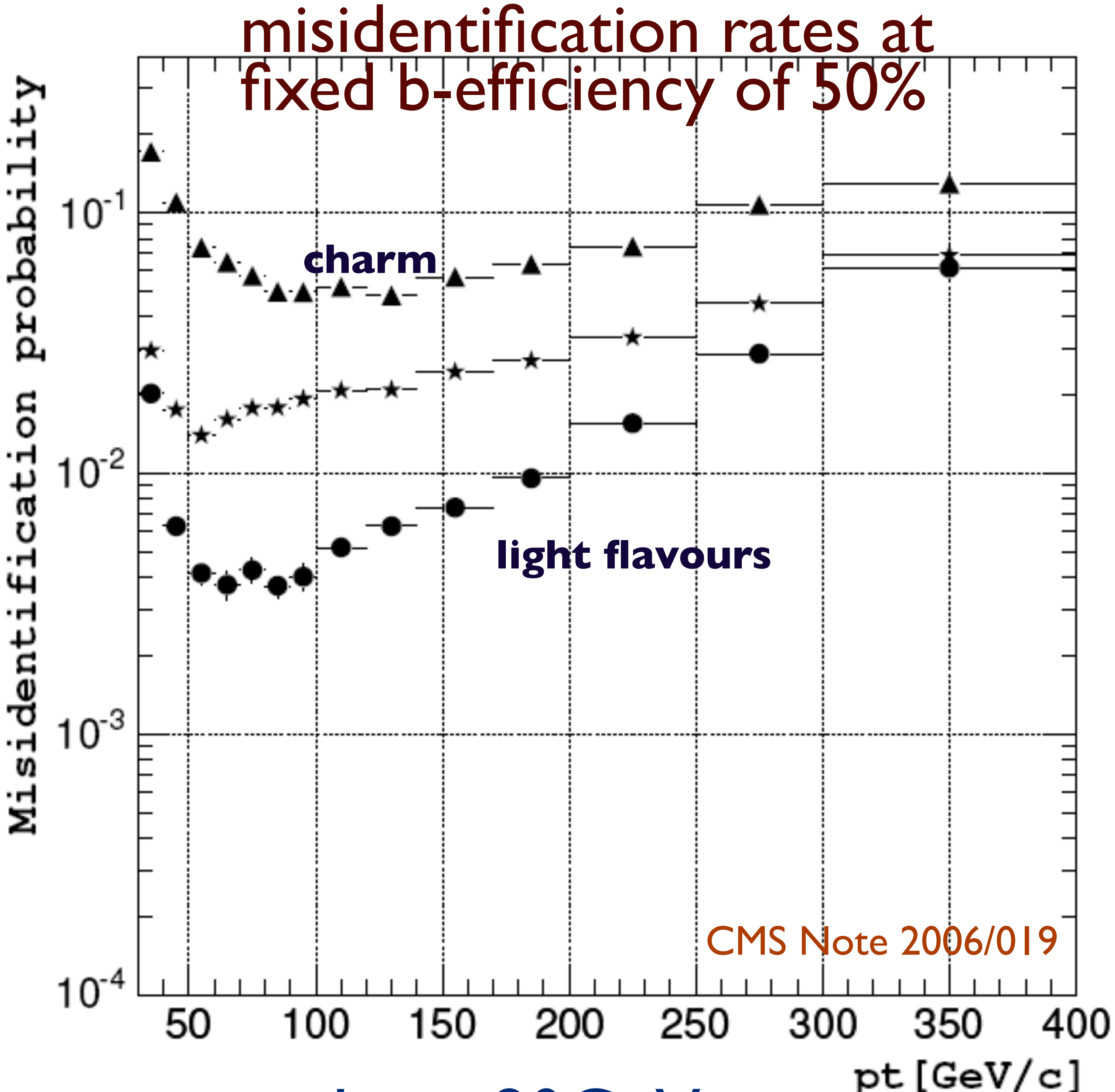
B. combined algorithm
- combining all available information
=> most performant algorithm
- requires training
- strongly affected by misalignment

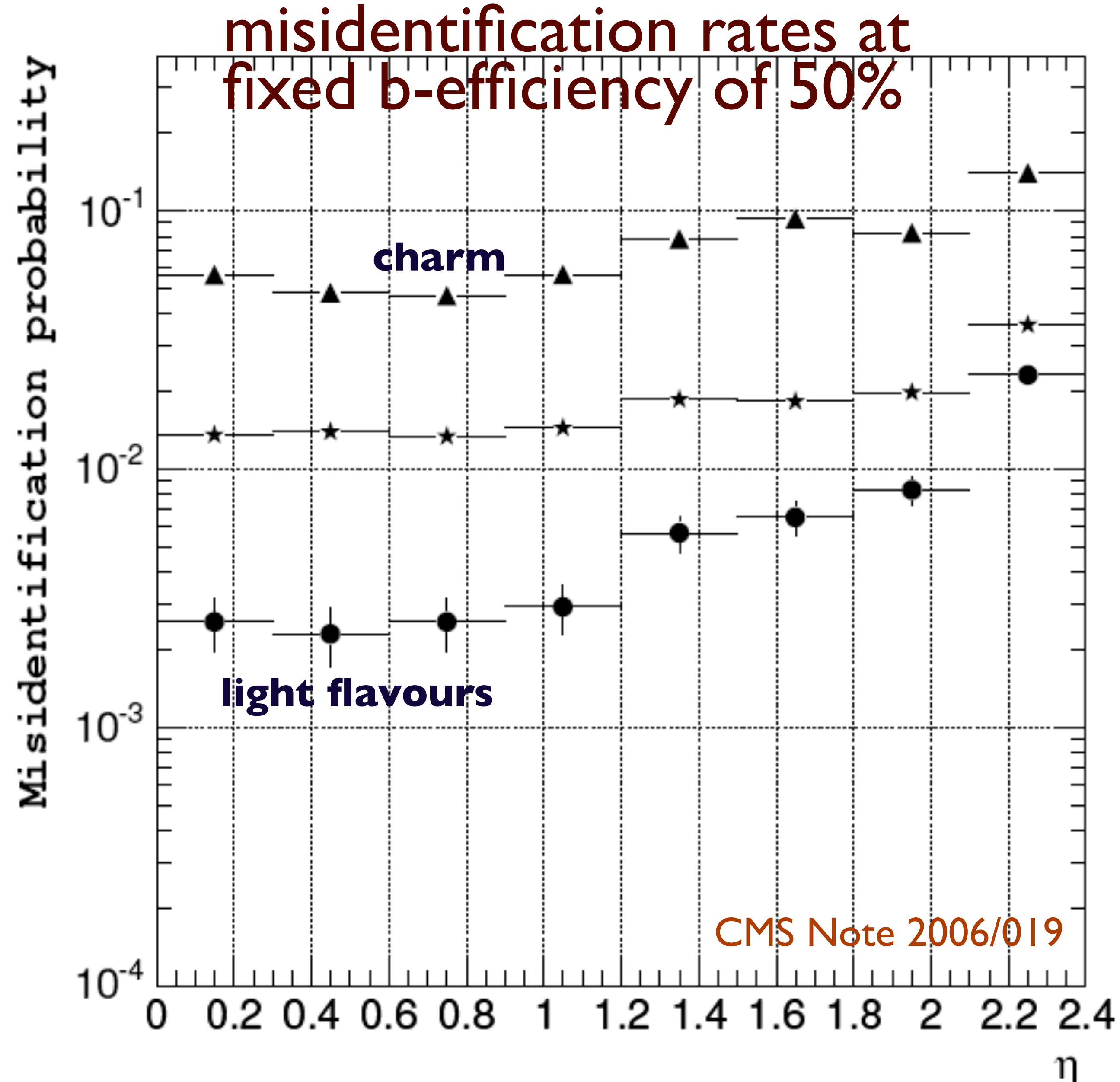
light flavour misidentification for combined algorithm:



Performance of b-Tagging (III)

performance depends on transverse momentum and pseudo-rapidity





optimal at ~80GeV
- degraded track quality at lower p_T (multiple scattering)
- at higher p_T increased track multiplicity and more difficult tracking in dense jets

optimal in the barrel
- higher material budget and worse detector resolution in forward region

Measurement of Inclusive b-Production (I)

study of differential cross sections of incl. b-production in a full detector simulation:

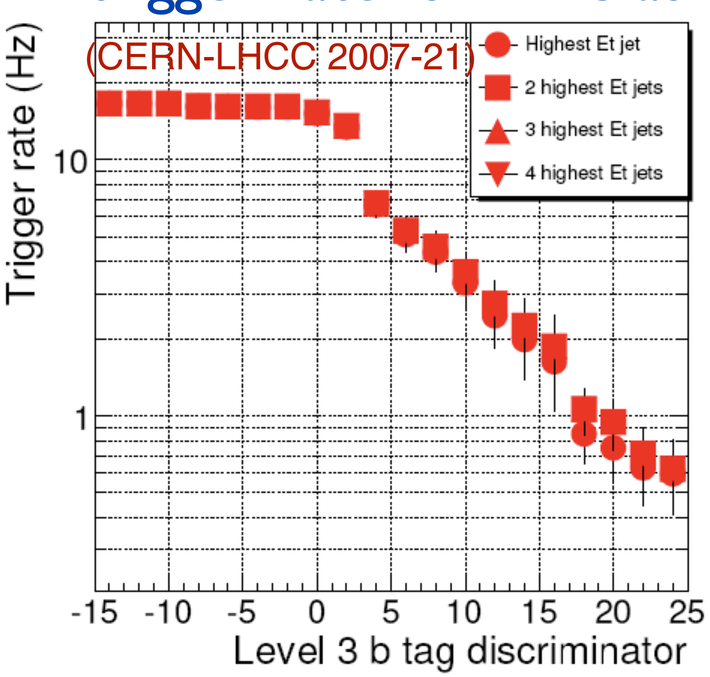
$\hat{p}_T$, GeV/c	σ^{QCD}, μb
$50-80$	20.9
$80-120$	3.0
$120-170$	0.5
$170-230$	0.1
$230-300$	2.4×10^{-2}
$300-380$	6.4×10^{-3}
$380-470$	1.9×10^{-3}
$470-600$	6.9×10^{-4}
$600-800$	2.0×10^{-4}
$800-1000$	3.6×10^{-5}
$1000-1400$	1.1×10^{-5}

- generated event samples for the simulation :
  QCD jets with PYTHIA containing 6% b-jets
  $t\bar{t}$ production as background $\sigma = 500\text{pb}$

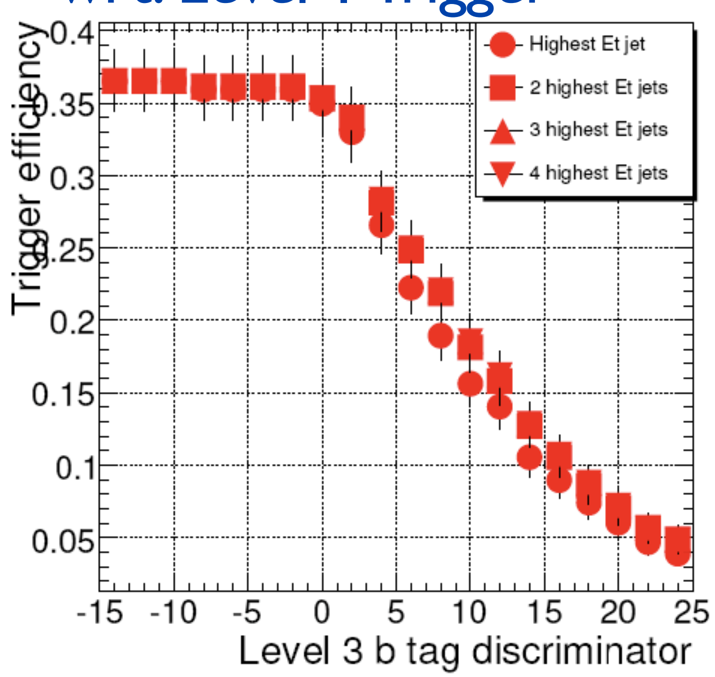
- Trigger: using a muon+b-jet trigger giving a total event rate of 6.1Hz at $\mathcal{L} = 2\times10^{33}\ \text{cm}^{-2}\,\text{s}^{-1}$

High Level Trigger can also use lifetime tagging algorithms:
(track counting algorithm)

trigger rate for minbias



trigger efficiency $t\bar{t}$ events wrt. Level 1 Trigger

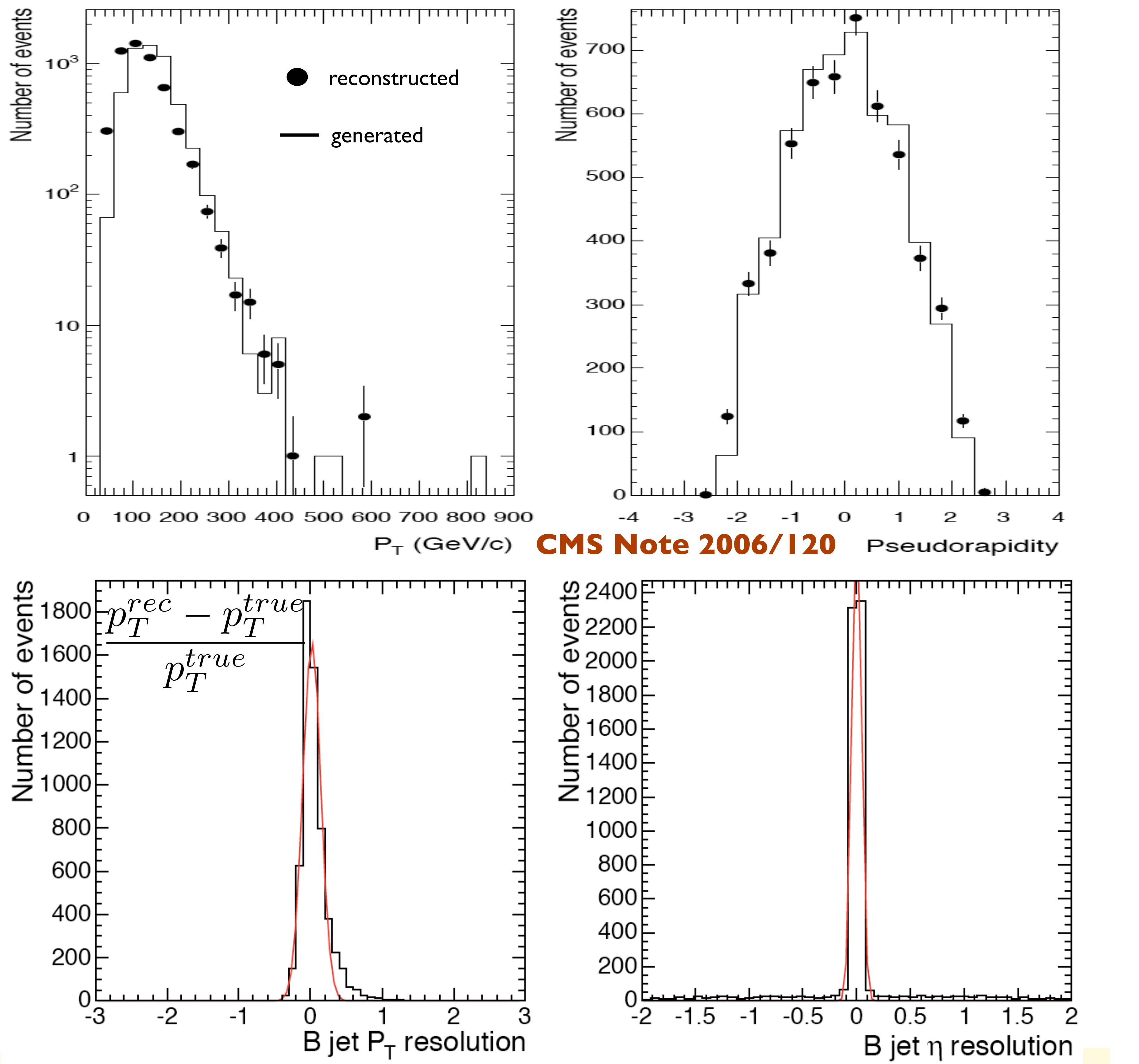


Measurement of Inclusive b-Production (II)

cross-section measured differential in p_T and eta.

=> transverse energy and pseudo-rapidity of jets need to be well reconstructed

p_T resolution of about 13% on average

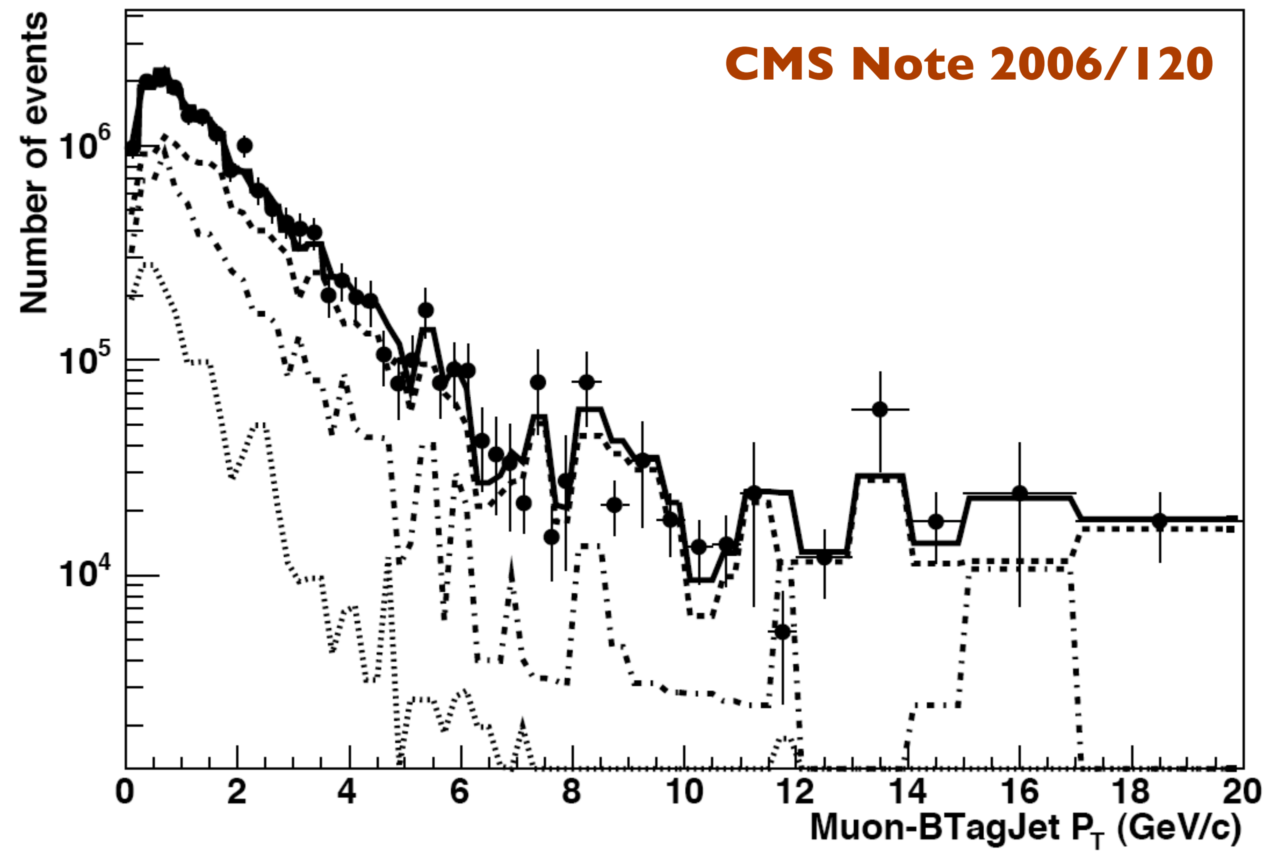


Measurement of Inclusive b-Production (III)

to measure the cross section, one needs:

1. number of selected events
2. integrated luminosity
3. signal selection efficiency
4. signal purity (flavour fraction)

=> measure 1. and 2.
for 3. and 4. rely as few as possible on simulation.



tagging efficiencies and flavour fractions can also be measured, e.g. by **fitting the relative transverse momentum of the muon to the jet**

=> can be done with a precision of about 10% for the b-content in $10fb^{-1}$
=> contamination from $t\bar{t}$ events is 1% for p_T<500GeV and 2.4% for p_T > 500 GeV

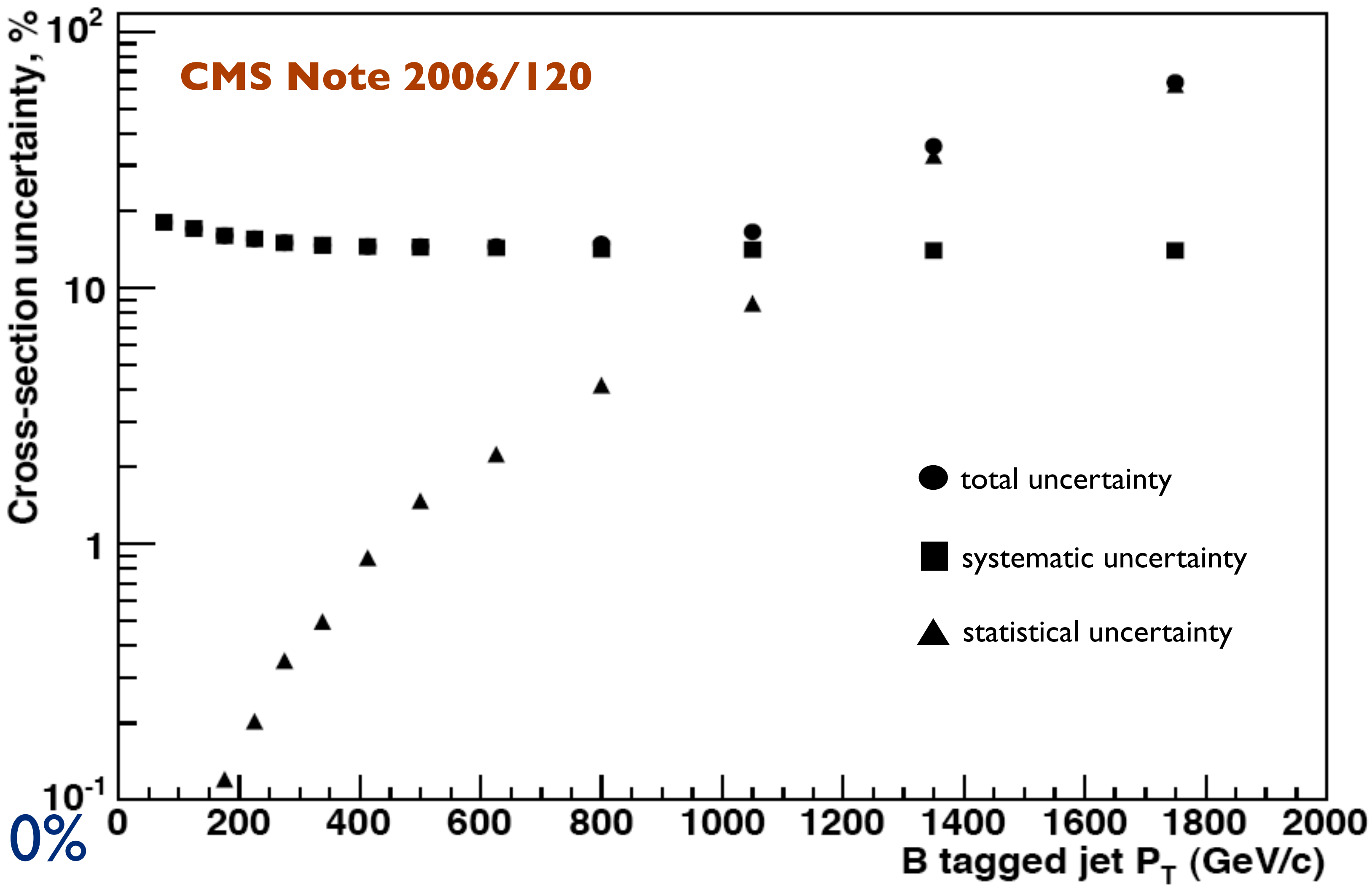
Measurement of Inclusive b-Production (IV)

systematic uncertainties taken into account:

- jet energy scale: 12%
  (depending on energy)
- model of detector response and lepton identification: 6%
- b-tagging: 5%
- luminosity: 5%
- trigger: < 3%
- fragmentation modeling

=>systematic uncertainty of 10% dominant below 1TeV

uncertainty depending on transverse momentum for $10fb^{-1}$:



=> measurement limited to 1.5TeV by statistical uncertainty

Measurement of b-Tagging Efficiencies

-top quarks: select high purity b-jet sample based on top quark observables: mass resonances, leptons, angles, ...

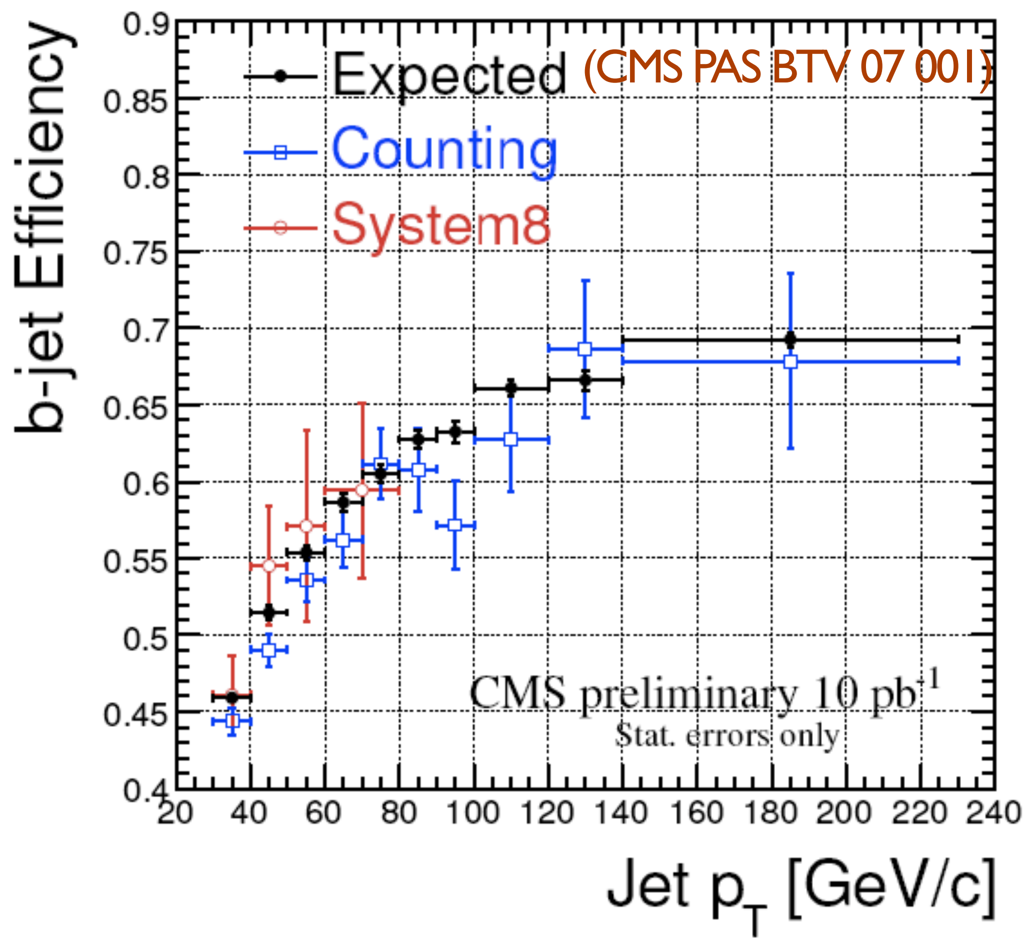
-muons in jets: fitting relative p_T of muon

-System8 method:

three uncorrelated identification criteria combined:

1. working point of (lifetime) algorithm
2. cut on muon P_{Trel}
3. presence of second b-tagged-jet (b-Quark pair production)

=> get system of 8 linear equations with 8 unknowns (flavour content)



-negative tags:

using the negative tail in the IP distribution to estimate mistagging rates

light flavour jets show symmetric distribution in the ideal case

=> negative tags allow measurement of mistagging rates with data

$$\varepsilon_{data}^{mistag} = \varepsilon_{data}^{-} \cdot R_{light}$$

can be done with 7% relative uncertainty for a mistag rate of 1%

(CMS PAS BTV 07 002)

Conclusions

- a large number of physics studies depend on efficient and clean identification of b-quark jets:

  Higgs physics, BSM searches, top physics, ...

- knowledge of $b\bar{b}$ production is crucial for these searches

- CMS will be able to measure the differential $b\bar{b}$ production cross section up to 1.5 TeV

- the tools to do this all seem to be in place

- detector commissioning is making good progress

  => waiting for data...